Multi-sensor Improved Sea-Surface Temperature (MISST) for IOOS – Navy component

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LONG-TERM GOALS

Ensure that Navy capabilities for a new generation of sea surface temperature products are coordinated with and benefitting from international research and development embodied by the Group for High Resolution Sea Surface Temperature (SST; GHRSST) and domestic capabilities demonstrated in the U.S. Integrated Ocean Observing System (IOOS) regions and applicable to regions around the world. This project is the Navy component of a broad national NOPP/IOOS/NASA MISST for IOOS project led by Chelle Gentemann. The Navy Participants under the ONR funding are Charlie Barron (NRL), James Cummings (NRL), Bruce McKenzie (NAVOCEANO), and Doug May (NAVOCEANO).

OBJECTIVES

The overarching objectives in MISST for IOOS are to continue producing GHRSST compliant satellite SSTs from existing and new sensors and to produce multi-sensor blended gap-free SSTs from US and international GHRSST datasets. The objectives of the Navy component are to coordinate Navy research and development with GHRSST through complementary tasks and interaction at the annual meetings, use of GHRSST data sets for assimilation and validation, and intercomparison of Navy and other GHRSST products. The Navy participants have work elements that support the five MISST for IOOS project tasks:

1. Computation of sensor-specific observational error characteristics required for optimal application and data fusion techniques.
2. Parameterization of IR and MW retrieval differences, with consideration of diurnal warming and cool-skin effects required for multi-sensor blending.
3. Retrospective reanalysis, continued NRT production, and dissemination of sensor-specific SST products with associated retrieval confidence, standard deviation (STD), and diurnal warming estimates to the application user community in the new GDS 2.0 GHRSST format.
4. Retrospective reanalysis, continued NRT production, and dissemination of improved multi-sensor high-resolution SST analyses in the new GDS 2.0 format, to demonstrate and optimize utility in IOOS and operational applications.

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5. Targeted applications of the SST analyses for the benefit of IOOS, including coral reefs, ocean modeling in the Gulf of Mexico, improved lake temperatures, numerical data assimilation by ocean models, numerical weather prediction, and operational ocean forecast models.

The Navy goal is to make more effective use of data streams and techniques developed by the collective MISST/GHRSST efforts. As a part of this cordination, the Navy component of MISST for IOOS evaluates regional application of Navy products that emphasizes performance in US coastal regions. This project will also work to leverage results of potential Navy interest from other MISST IOOS performers.

APPROACH

Under the Navy component of MISST for IOOS, specific tasks have been identified to leverage and extend existing work in a way that furthers development of operational Navy capabilites and supports the broader MISST for IOOS objectives. In addition to participating in the GHRSST meetings with the MISST team, the Navy tasks for 2013 are

1. Process and distribute L2P VIIRS and METOP-B GAC, and N-19 LAC (May and McKenzie)
2. Implement new and existing FNMOC/NCODA SSTs in GDS 2.0 (Cummings).
3. Evaluate impact of new NAVOCEANO/ MISST data streams in NAVOCEANO assimilative ocean models on IOOS regional SST analyses and forecasts (Barron).
4. Disseminate NOGAPS diurnal SST model output for validation. (Cummings)
5. Add new MISST data sets and error estimates to the coupled model system and evaluate the sensitivites of the atmospheric model. (Cummings).

WORK COMPLETED

1. NAVO is currently generating the following L2P data sets for GHRSST: NOAA-18 GAC, NOAA-19 GAC, NOAA 19 LAC, METOP-A GAC, METOP-A FRAC,and Suomi NPP. NAVOCEANO is ready to begin dissemination of METOP-B GAC and METOP-B FRAC. NAVOCEANO began dissemination of NPP L2P SST data to the PODAAC on 21 May 2013. NAVOCEANO switched all L2P data sets to GDS v2.0 on 31 July 2013. NAVO has a reader for the MSG SST data in GDS v2.0 format; this data is pulled directly from the data provider. VIIRS cloud screening has been been evaluated with comparisons of the VIIRS Cloud Mask IP with NAVO Cloud Mask. NAVOCEANO continues to request that other data providers also include brightness temperatures in SST observation records.
2. Readers have been implemented to use GDS 2.0.
3. Evaluations were reported examining different GHRSST and NAVOCEANO data streams in the Gulf of Mexico (IOOS-region) and the Mediterranean Sea focuising on the interaction of the new data streams with alternate data assimilation approaches under conditions of diurnal warming. 3DVAR with and without First Guess at Appropriate time showed different levels of effectiveness depending on the amplitude and timing of diurnal variations relative to the nowcast analysis time and forecast length.
4. Prepared report on the SST data impact in global HYCOM.
5. Prepared report on the direct assimilation of Satellite SST radiances.

6. All results were reported during GHRSST XIV, the annual meeting held this year at Woods Hole, MA.

RESULTS

An adjoint-based procedure to determine the impact of assimilation of observations on reducing ocean model forecast error has been integrated into the Navy's global HYCOM ocean analysis/forecast system (Cummings and Smedstad, 2013). Adjoint sensitivity gradients and actual model-data differences are used to estimate the impact of each observation assimilated on a measure of model forecast error (Langland and Baker, 2004). It is not necessary for an observation to produce a large change in the model initial conditions to have a large impact on reducing model forecast error. Observations with small model-data differences can have large impacts when the observation influences a dynamically sensitive location. The method provides a feasible all at once approach for determining observation impacts. The procedure is computationally inexpensive and can be used for routine observation monitoring. Data impacts can be partitioned for any subset of the data assimilated: instrument type, observed variable, geographic region, vertical level, or platform with traceability to individual platforms based on call sign. Results presented here show the impact of assimilation of the various SST observing systems on reducing HYCOM 48-hour temperature forecast error.

A capability for direct assimilation of satellite sea surface temperature (SST) radiances has been implemented in the three-dimensional variational Navy Coupled Ocean Data Assimilation system (NCODA 3DVAR). The SST radiance assimilation operator uses both forward and inverse modeling based on radiative transfer. The operator uses an incremental approach and takes as input prior estimates of variables known to affect SST: (1) SST, (2) air temperature, and (3) water vapor. The priors are obtained from ocean and numerical weather prediction (NWP) model forecasts. The forward model uses the Community Radiative Transfer Model (CRTM) to simulate top-of-the-atmosphere (TOA) brightness temperatures (BTs) for the various SST satellites and channel wavelengths. The inverse model is forced by differences between observed and predicted TOA-BTs and uses CRTM Jacobians (radiance derivatives with respect to the priors) to retrieve information about the priors from the radiance measurements. The SST inverse model effectively partitions the observed change in TOA-BT into a change in SST that takes into account the variable temperature and water vapor content of the atmosphere at the time and location of the satellite SST radiance measurement. The change in SST is then input as an innovation in the NCODA 3DVAR minimization. Proper characterization of the prior errors is critical to the success of the method. For this purpose, atmospheric ensemble products are used to provide uncertainty of the NWP priors, radiometric noise estimates of the channels are obtained from satellite monitoring statistics, and SST prior errors are estimated from a time history of ocean model variability and model-data differences. The method is a true example of coupled data assimilation, whereby an observation in one fluid (atmospheric radiances) creates an innovation in the other fluid (ocean SST).

Sea surface temperature (SST) varies on a range of temporal scales according to variations in insolation, advection, and mixing. A prominent diurnal signal can frequently be identified in the SST of midlatitude to tropical regions, particularly under conditions of high insolation and low wind speed. Case studies in the Gulf of Mexico and Mediterranean Sea are used to examine the impact of such variations on assimilative SST analyses and forecasts. The scenarios provide infrared observations from polar-orbiting or geostationary satellites to an assimilative ocean model using a 24-hour update cycle. SST innovations are determined relative to the prior 24-hour SST forecast or using a first guess at the appropriate time (FGAT) approach which matches each observation to its corresponding time-

varying forecast. It was anticipated that the FGAT would have its largest impact in the Gulf of Mexico summer, when the occurrence of the relatively large diurnal cycle maximum is nearly in phase with the nowcast. In contrast, FGAT was anticipated to have relatively little impact in the Mediterranean summer, where the diurnal maximum and nowcast are 90° out of phase. The impact of FGAT in the fall-spring seasons would be more affected by the skill in forecasts of the non-diurnal trend, as the diurnal signal is smaller in these seasons. FGAT is found to have its largest benefit in reduction in the mean error of the SST forecasts; its impact on standard deviation is mixed. It is also found to have larger impact in the cases assimilating observations from geostationary satellites, which give a broad sample of SST over all times of the day. Observations from the polar orbiter come at a sun-synchronous 10:00 AM or PM, sampling near the midpoints of the diurnal variation. The effectiveness of FGAT is dependent on model forecast skill and effective only if the model is able to adequately predict diurnal or other dominant variations between analysis times.

IMPACT/APPLICATIONS

Provision of the NAVOCEANO-processed SST retrievals in the GDS 2.0 format will encourage broader adoption of the common standard, reducing the cost associated with maintaining different formats and simplificing the inclusion of other data streams into Navy systems.

The perfomance evaluations have highlighted the forcast sensitivity to heat flux biases and led to new ways to evaluate and interpret forecast skill and uncertainty. It has also led to successful proposals funding new research into methods to combine satellite observations with 4DVAR assimilation systems to reduce forecast bias.

The atmospheric corrections via physical SST retrievals will provide more accurate SST retrievals for calculations of sensible heat flux between the atmosphere and ocean. This in turn will provide more accurate hindcast and forecast smodel results, particularly when coupled with 4DVAR to extend the hindcast corrections into the forecast period.

TRANSITIONS

Use and provision of GDS 2.0 data has transitioned into operations at NAVOCEANO and FNMOC to be used. Assimilation of the new SST data streams through radiances and direct SST estimates and advances in tratment of multiple data streams in the presence of diurnal SST variations is reducing error and extending useful forcast duration for Navy forecasts in the atmosphere and ocean. Additional capabilities are in the process of transitioning to these operational centers, to be used in daily assimilative analyses and forecasts.

RELATED PROJECTS

6.4 SPAWAR Interface analysis from satellite – ocean. Supports development and transition to Navy operations at NAVOCEANO and FNMOC of capabilities using satellite observations to estimate SST radiances, bulk SST, and heat fluxes across the air-sea interface. MISST for IOOS adds an IOOS emphasis for evaluation of these capabilities.

PUBLICATIONS

1. Cummings, J. and O.M. Smedstad 2013: Variational Data Assimilation for the Global Ocean. In, Data Assimilation for Atmospheric, Oceanic & Hydrologic Applications (Vol. II). S. Park and L. Xu (eds). Springer, pp. 303-343.
2. McLay, J.G., M.K. Flatau, C. Reynolds, J.. Cummings, T.F. Hogan, and P Flatau, 2012: Inclusion of Sea-surface Temperature Variation in the U.S. Navy Ensemble-transform Global Ensemble Prediction System. *Journal of Geophysical Research*, **117**, 1-24.